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Quantum tunnelling conductive metal-polymer composites

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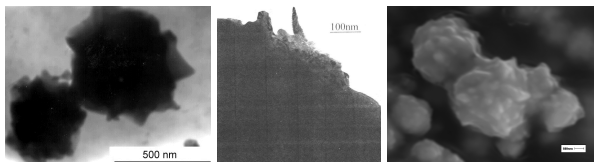
abstract

A small, local, high technology materials development company, Peratech, has invented a new type of metal-polymer composite using a metallic powder encapsulated within a silicone rubber matrix. Compared to other insulator-conductor composites, the Peratech material displays unique and fascinating electrical characteristics. In 1996, collaborative work began between Peratech and the University of Durham on this new breed of 'smart' material, with the aim of understanding its complex physics and to aid in the development of commercial applications. Since then, Peratech have received numerous awards for their new composite and innovative ideas.

The micron-sized metallic particles within the Peratech material have a uniquely spiky surface morphology. The resulting composite is intrinsically highly electrically insulating, but displays a drastic reduction in resistivity to a value close to that of metals when compressed under only finger pressure. Contrary to 'conventional' composites, the resistivity also drops when the material is subjected to tension, or any type of mechanical deformation. In addition, the current-voltage characteristics of the composite are highly non-linear and display hysteresis, giving rise to switching behaviour and a negative differential resistance regime. The composite also displays a thermostatic positive temperature coefficient (PTC) effect, and is capable of carrying currents as large as 3A without observable damage. The cause of such phenomena is thought to be due to the quantum-mechanical tunnelling of electrons between adjacent metallic particles.

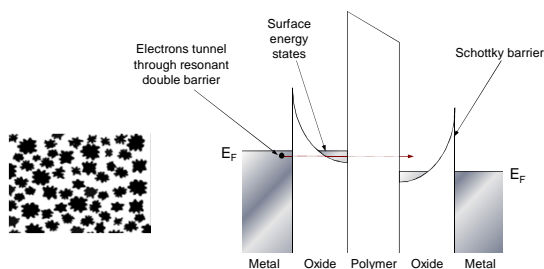
This new breed of material has paved the way for a new family of quantum tunnelling composites (QTCs). Such materials can be woven into fabrics or coated onto virtually any surface, enabling new and exciting "touch sensitive" technologies such as wearable electronics to be developed. Other applications include electromagnetic interference (EMI) shielding, pressure sensors, reusable fuses, conductive adhesives and artificial olfactory systems.

microstructure and conduction mechanism



SEM and TEM images of metal particles within the Peratech composite

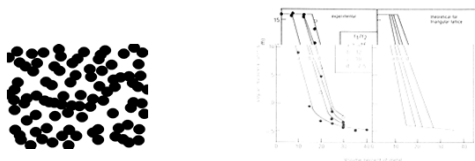
- Micron-sized conducting (metal) particles mixed randomly within a non-conducting (polymer) matrix
- Metal particles have irregular, spiky surface structure
- Spikes generate high charge densities
- Conduction by quantum mechanical tunnelling of electrons via spikes
- Accounts for high electrical sensitivity to applied pressure



Electrical conduction mechanism via the tunnelling of electrons from spikes

'conventional' composites

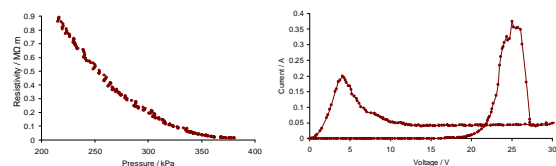
- Researched for over 40 years
- Metal particles usually have smooth, rounded shape
- Electrical conduction when neighbouring particles touch each other
- Conduction by "percolation"



Electrical conduction via "percolation" within a 'conventional' composite

properties of peratech composite

- Intrinsically electrically non-conducting
- Conductivity increases dramatically when compressed or stretched ($10^{12}\Omega$ to 1Ω under only fingertip pressure)
- Far greater sensitivity than 'conventional' composites
- Destruction of spikes leads to decreased sensitivity
- Highly non-linear current-voltage characteristics with hysteresis



Typical electrical characteristics of the Peratech composite

applications



Making fabrics and surfaces touch sensitive: - An interface for an MP3 player in the sleeve of a jacket and a power-drill 'easy-grip' variable speed control

- Pressure / tension sensors
- Re-usable fuses
- Conductive adhesives
- Electromagnetic interference (EMI) shielding
- Touch sensitive fabrics – wearable electronics
- Interactive aids for the visually impaired, or for those with coordination difficulties
- Gas and vapour sensors / electronic noses



Awards: Tees Valley Technology Award, SMART Award Winner, Millennium Product Status, Saatchi & Saatchi International Award for Innovation in Communication

I acknowledge the members of Peratech Ltd., the Optoelectronics Research Group and Andrew Yates of the Durham Semiconductor Research Group for his microscopy work.

For more information about this work, please visit www.dur.ac.uk/opto.electronics or www.peratech.co.uk